

# In-flight Flat-fielding of the Extreme-ultraviolet Imaging Telescope

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## Why does EIT need a new flat-field ?

The flat-field (i.e. the map of the pixel to pixel response) of the EIT CCD was calibrated during the pre-flight calibrations (Figure 1). Unfortunately, the response of the CCD degrades as it accumulates EUV dose (Figure 3). "Bake-outs" of the CCD are performed every few months to recover part of the nominal sensitivity of the detector. But bake-outs must be very long to be effective, and even the artificial three-months bake-out of summer 1998 during the loss of *SOHO* could not completely clean up the CCD. Therefore, a regular three-days bake-out can not restore the nominal sensitivity of the detector, and the upper envelope of the response curve decreases. The degradation of the detector being a function of the total EUV dose, it is not uniform across the detector. Since EIT does not have on-board EUV flat-fielding capability, the actual flat-field is completely unknown. The need for a new flat-field is urgent because without it, recent EIT data are completely useless for photometric measurements.

We recently discovered that there is a linear relation between a flat-field obtained for one date and a flat-field obtained for any other previous date. Therefore, although the response of the CCD varies from exposure to exposure, only one flat-field is enough to correct all the EIT images from the beginning of the mission until the date when this flat-field was obtained. We actually have only flat-field available for 1998, June 24. But since this flat-field does not contain the EUV dose history information after this date, it gives a bad correction when applied to the second half of the EIT archive. We must therefore update the EIT flat-field, and we will see that one solution is to offpoint *SOHO*.

## How to get a new flat-field : the Kuhn algorithm

The Kuhn algorithm (Kuhn and Loran 1991) is a smart way to reconstruct the flat-field of a detector from a set of shifted images of a same object. The only restriction of this technique is that it can not determine the absolute value of the gain, but only its variations. In other words, the gain of the detector is given only to within an overall multiplicative constant. The displacements between individual frames should be wisely chosen in order to guarantee the rapid convergence of the algorithm. First, the displacement vectors should not be colinear if one wants to map the flat-field in both  $x$  and  $y$  directions. Second, the offsets between the

images should have no common multiples because otherwise adjacent pixels cannot be linked by the iteration algorithm.

In order to demonstrate that an accurate flat-field of EIT can be obtained by performing an offpoint of *SOHO* that matches these specifications, we will present the results of the Kuhn algorithm on simulated data reproducing the observing conditions during an offpoint. Then, we will present a tentative timeline for a future offpoint of *SOHO*.

## Simulations

We tested the validity of the Kuhn algorithm when applied to EIT images. As we will see in the next section, the maximum possible cadence during an offpoint is about 6 minutes. Therefore, in order to reproduce realistic observing conditions, we chose a set of 19.5 nm images recorded on October 18, 1998 at a 7 minutes cadence. We corrected the raw images using a rescaling of the best-guess flat-field that we have at this time (showed on Figure 2). We chose the shifts between images as being prime numbers in pixels. The maximum deviation from the nominal pointing is 383 arc seconds. The data outside the original field of view were created by extrapolation. We then multiplied the resulting shifted images by the best-guess flat-field. Figure 6 shows the resulting simulated data set. The output of the Kuhn algorithm after 100 iterations is shown on the left panel of Figure 6. The comparison with the original flat-field of Figure 2 reveals almost no differences. Indeed, the right panel of Figure 6 shows that the residuals don't exceed a few per cent. On earlier tests of the Kuhn algorithm on EIT images, we noticed the presence of low frequency artifacts in the extracted flat-field. But these tests were done with fewer iterations (not more than 20) and the artifacts disappear only when a sufficient number of iterations is performed (about 100). These simulations show that we can reconstruct a reliable flat field of the EIT CCD by using the data acquired during a properly designed offpoint. The variations in the solar image between the beginning and the end of the sequence (about an hour) introduce only negligible noise. Note that if a large solar event was to appear during the real offpoint (a large CME for example), it is possible to run the algorithm after masking of the affected parts of the images.

- Two offpoints are needed, in order to map the flat-field on both  $x$  and  $y$  axis. The optimum would be to have negative and positive shifts on both axis.
- A total of about 10 pointing positions is needed in order to correctly sample the whole range of spatial frequencies.

- The shifts in EIT pixels between the images must not have any common factor in order to guarantee the connection of adjacent pixels by the iterative algorithm.
- The maximal shifts between the images must be at least between -100 and 100 pixels ( $\pm 260$  arc seconds).
- The images must be as close in time as possible in order to minimize the residual solar structures.

The minimum time difference between images is imposed by the spacecraft specifications. Whatever the amplitude of the steps, it takes 6 minutes to go from one position to another. The acceleration and deceleration profiles ensure that there is no stabilization time when reaching a pointing position. Considering the possibility of a delay in the planning, synchronization between the stepping and the EIT exposures cannot be achieved by loading a plan. We need to have about one minute of NRT at each step to manually take the exposures. We will take at each step a half res 304 Å image (512x512) and a full res 195 Å image. It takes about three minutes to process the 304 Å image, and 10 seconds to take the 195 Å image. Adding 15 seconds of overhead to let us make sure the images were taken, we need the spacecraft to stay still for about three and a half minutes at each pointing position. Considering these requirements and the fact that MDI could take better advantage of this offpoint with slightly longer stops, we settled for four minute dwells. We will therefore achieve a 10 minutes cadence. Here is the updated timeline :

<b>start position (arc sec)</b>	<b>end position (arc sec)</b>	<b>dwell (minutes)</b>	<b>time from beginning (min.)</b>
(0, 0)	(0,0)		0
(0, 0)	(-225, 0)	4	10
(-225, 0)	(-100, 0)	4	20
(-100, 0)	(0, 0)	4	30
(0, 0)	(68, 0)	4	40
(68, 0)	(383, 0)	4	50
(383, 0)	(0, 0)	4	60
(0, 0)	(0, -225)	4	70
(0, -225)	(0, -100)	4	80
(0, -100)	(0, 0)	4	90
(0, 0)	(0, 68)	4	100
(0, 68)	(0, 383)	4	110
(0, 383)	(0, 30)	4	120
(0, 30)	(0, 0)		130

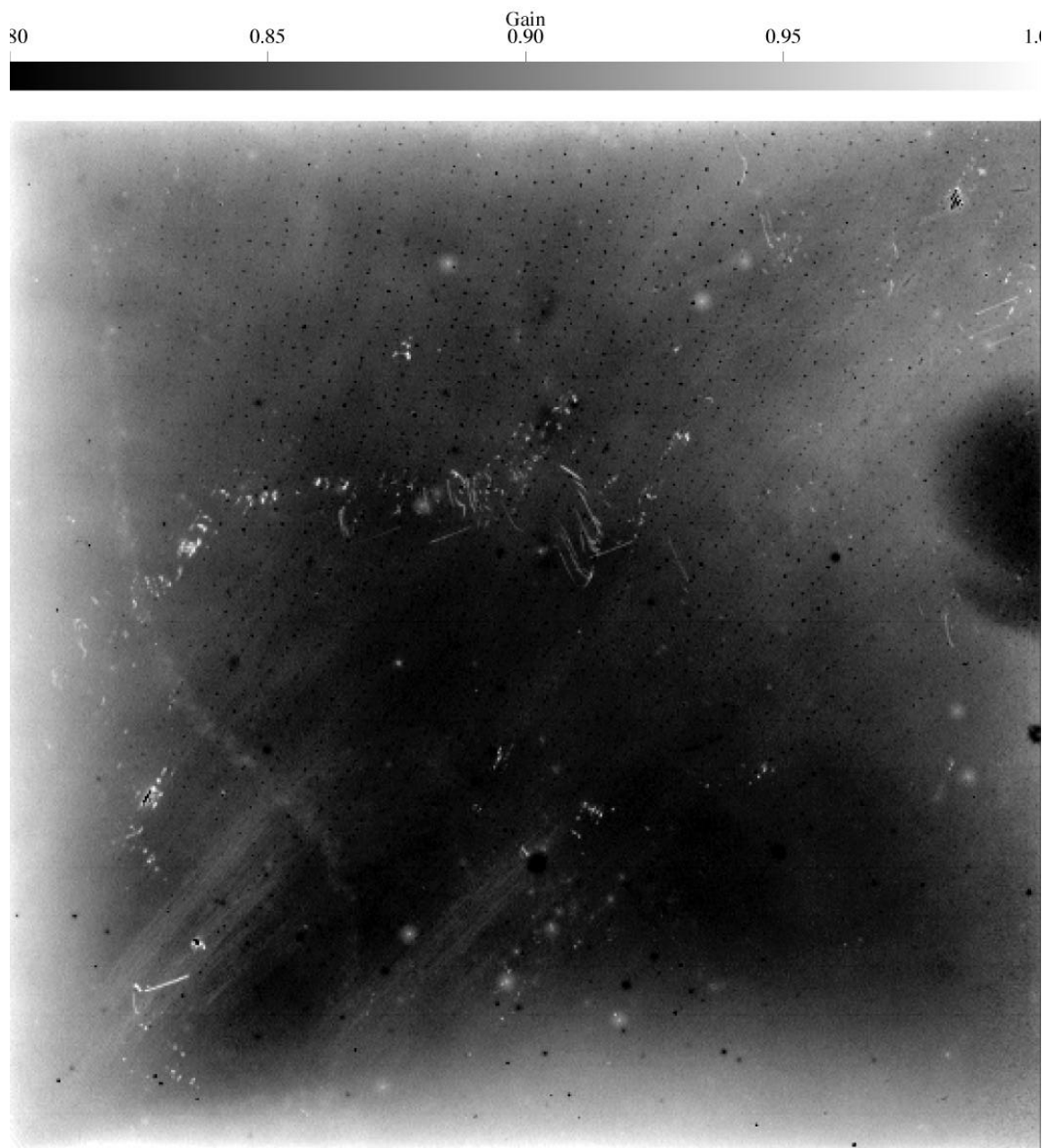
The final stop at (0, 30) was requested by the LASCO team to perform pointing calibrations. EIT will use it to get an extra set of images.

The stop times might have to be a little longer in the final timeline, but are consistent with what is possible to do. Since by offpointing too much the algorithm loses the connection between distant areas of the images, it is preferable to have positive and negative shifts on each axis to achieve a more precise reconstruction

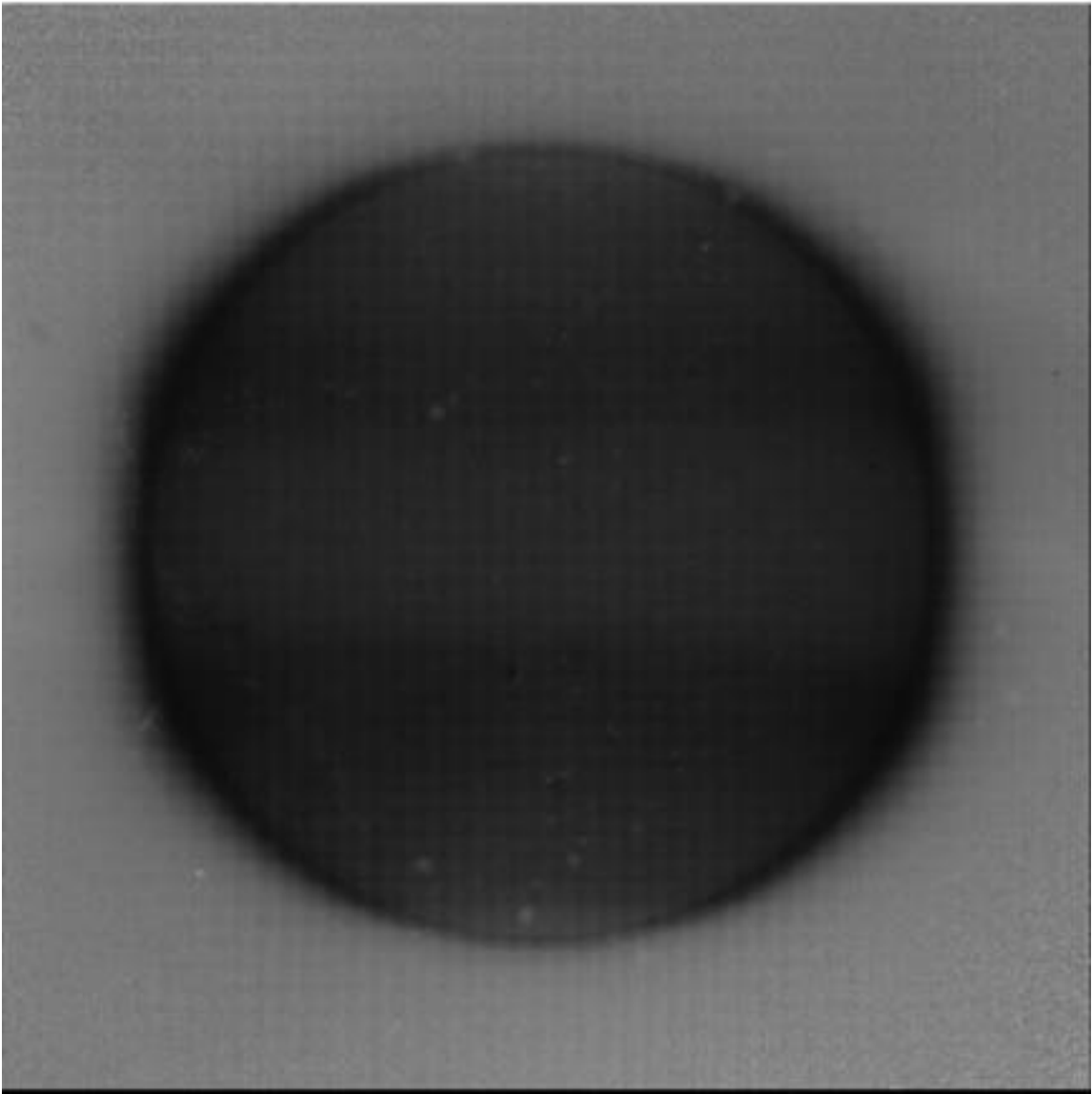
## **Bibliography**

Kuhn, J. R. and Lorz, D. 1991, *Gain Calibrating Non Uniform Image-Array Data Using Only the Image Data*, Publ. Astron. Soc. Pac., **103**, 1097-1108

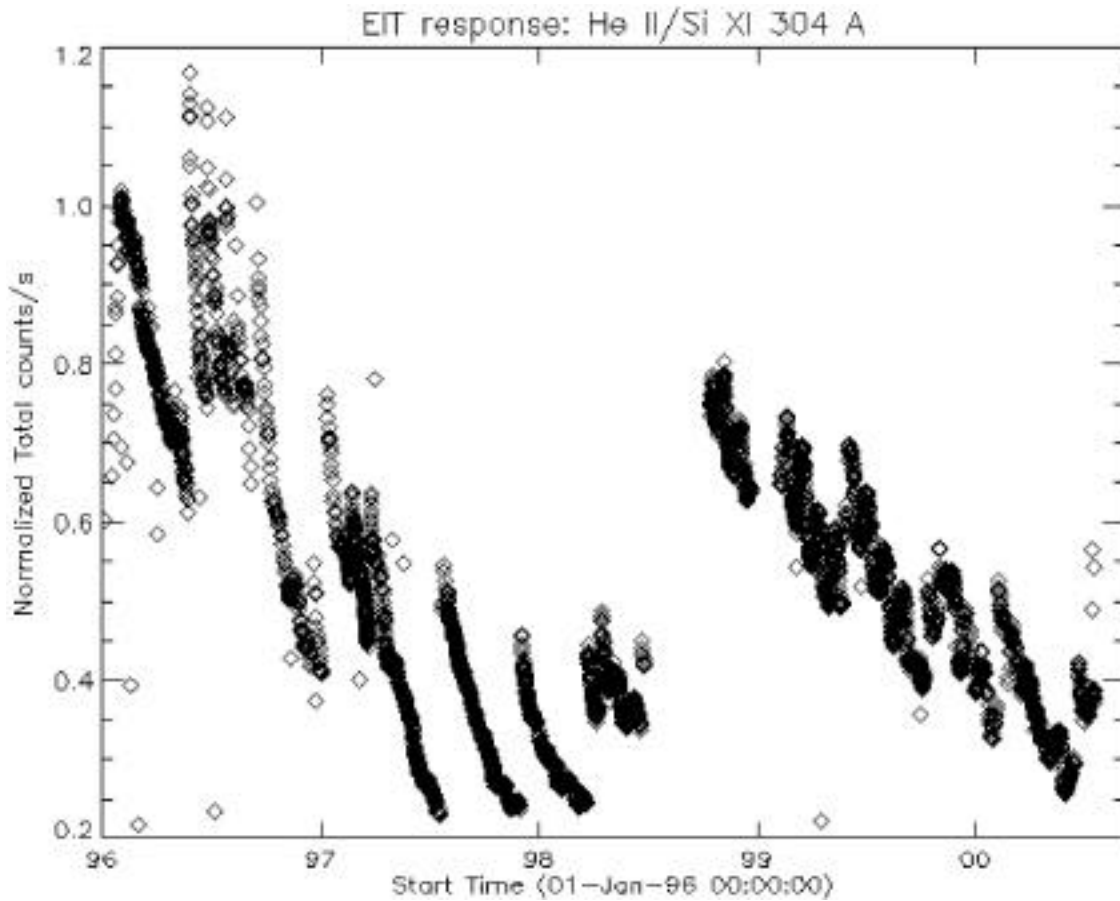
## Figures



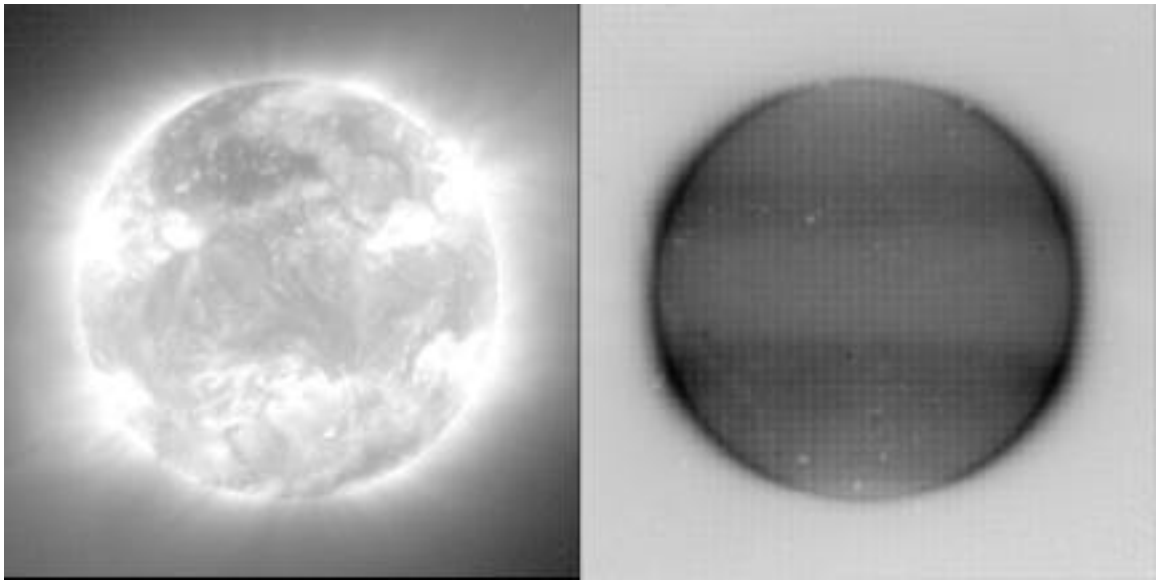
**Figure 1.** The 195 Å pre-flight flat-field



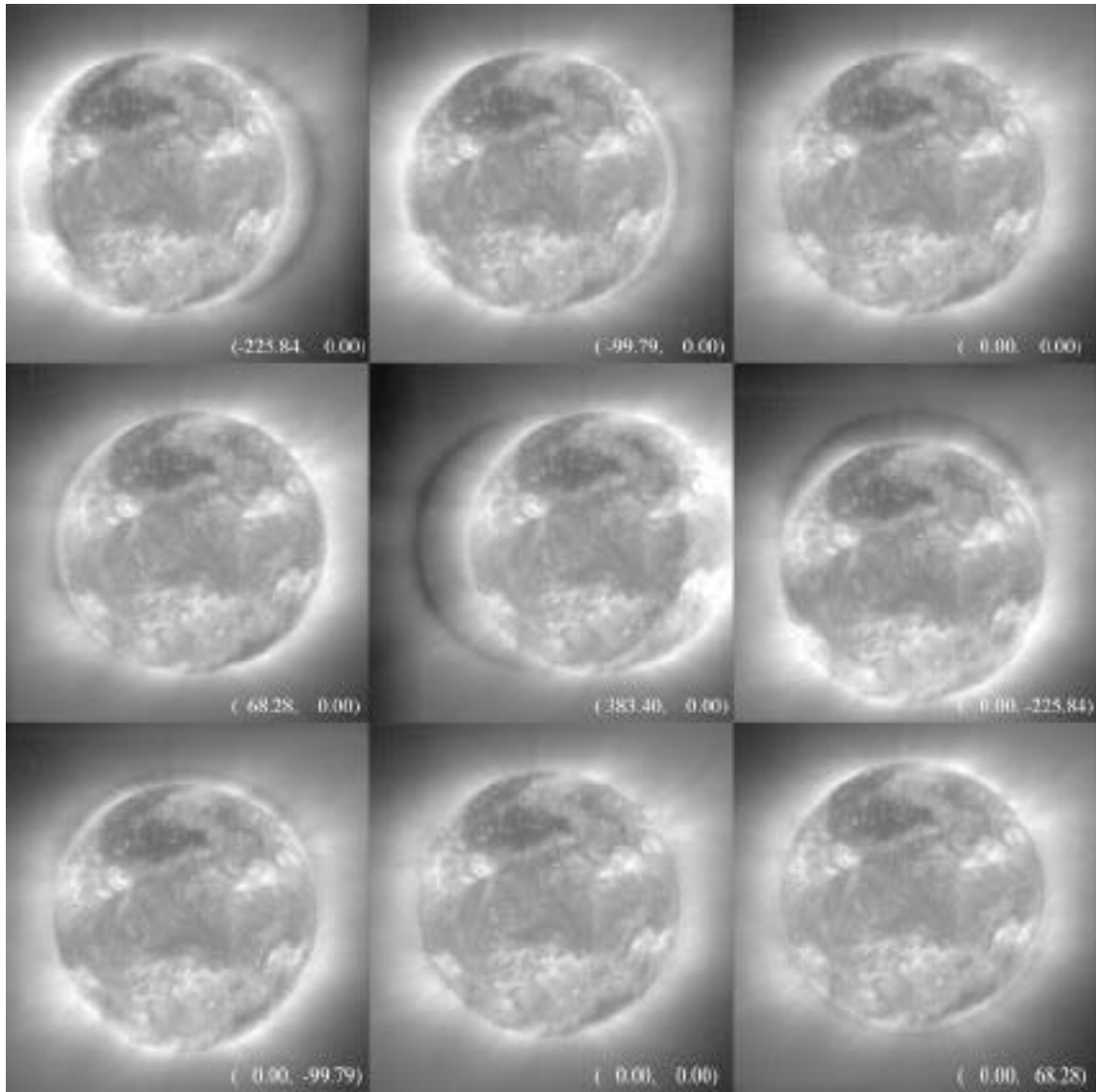
**Figure 2.** The 195 Å flat-field obtained using the ESR of June 24, 1998. Compare this flat-field with the relatively uniform pre-flight flat-field of Figure 1. The scratches and spots of the pre-flight flat-field are still visible, but now, because the solar disc is always focused at the same position on the detector, the gain reproduces a negative 19.5 nm image. Being the brightest in the images, the limb is the most degraded, at about 10% of the nominal response.



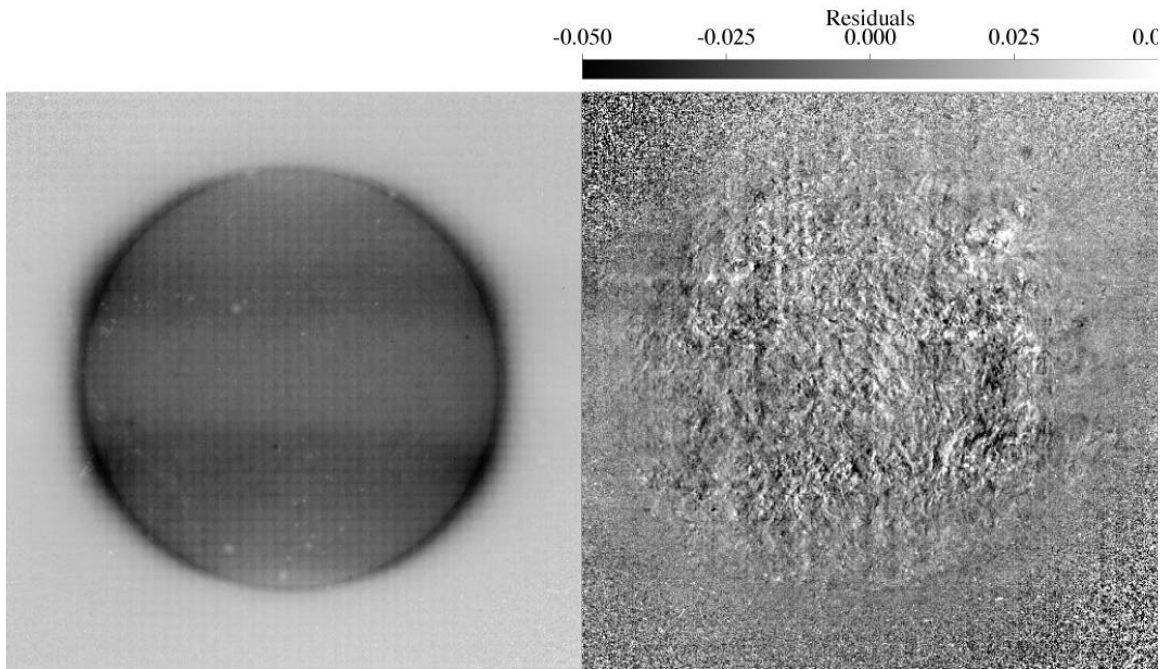
**Figure 3.** The total counts in the 304 Å EIT images since the beginning of the mission, normalized to the early 1996 February response. Between two bake-outs, the overall response of the CCD decreases exponentially with time. Because it is impossible to perform long enough bake-outs to completely counterbalance the degradation, the upper envelope of the curve decreases. The actual response is about one third of its nominal value.



**Figure 4.** One of the test images (*left panel*) and the test flat-field (*right panel*).



**Figure 5.** The simulated data set used to test the Kuhn algorithm. Each image is the multiplication of a shifted test image by the test flat-field of Figure 1. The shifts in arc seconds are noted in the lower right corner of the images.



**Figure 6.** Left : the flat-field extracted from the data set of Figure 5. Visually, no differences are noticeable from the original flat-field of Figure 2. Right : The residuals don't exceed a few per cent.